Emergency Department Visits and Hospitalizations for Respiratory Disease on the Island of Hawaii, 1981 to 1991

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This study examined trends in and patterns of emergency department visits and hospitalizations for respiratory disease on the island of Hawaii from 1981 to 1991. We found that emergency department visit rates and hospitalization rates for both asthma and COPD for 1987 to 1991 increased in all regions of the island in comparison with such rates for 1981 to 1986. Rates of emergency department visits and hospitalizations for chronic obstructive pulmonary disease or COPD, but not asthma, were significantly higher in the high-exposure Kona side of the island than in the intermittent-exposure Hilo side of the island during 1983 and 1988 to 1990. We also found that during the weeks that winds were from the west, blowing volcanic air pollution toward Hilo, emergency department visits for asthma increased 15%. Some of the results of our study support the hypothesis that volcanic air pollution affects respiratory health on the island of Hawaii, while other results do not. Any future studies should include measurements of air pollutant levels.

Introduction

Morbidity and mortality among people with asthma or COPD continue to increase in the United States.[1,2] Hawaii has one of the highest asthma death rates in the United States.[3] Many factors may contribute to this problem, including lack of access to medical care, inappropriate use of medications, exposure to allergens, and poor air quality.[4] We undertook this study of emergency department visits and hospitalizations for exacerbations of asthma and COPD among persons living on the island of Hawaii to determine the possible effect of the change in air quality that occurred in 1986 as a result of the eruption of Hawaii's Kilauea Volcano.

Kilauea Volcano has been active intermittently since 1983 and continuously since 1986. The main volcano and its vents produce about 1200 tons of sulfur dioxide gas daily. Prevailing winds blow most of this gas, along with its oxidation products, to the western side of the island where Kona is located. The island's main population center, Hilo, is located about 40 miles east of the Kilauea Volcano. Occasionally the winds reverse and blow from the west to the east, toward Hilo. During 1989 to 1990 mean levels of particulates with an aerodynamic diameter of less than 10 μm on the Kona and Hilo sides of the island were similar (11.5 $\mu g/m^3$ and 10.7 $\mu g/m^3$, respectively), whereas sulfate levels (which are thought to be related to volcano-generated air pollution) were higher on the Kona side (4.7 $\mu g/m^3$) than on the Hilo side (1.8 $\mu g/m^3$) of the island.[5]

In the first part of this study we examined trends in the rates of emergency department visits and hospitalizations from the emergency department for asthma and COPD that occurred on the island of Hawaii from 1981 to 1991. In the second part of this study we examined weekly variations in emergency department visits for asthma that occurred at Hilo Hospital from 1981 to 1991. For the years 1986 to 1991, the years for which we have meteorologic data available, we examined how wind speed, wind direction, and temperature affected emergency department visits for asthma at Hilo Hospital.

Methods Part I

Researchers extracted records from emergency department log books in four of five hospitals (Hilo, Kau, Kona, Kohala) on the island of Hawaii for the period from January 1, 1981 to September 30, 1991. The fifth hospital at Honokaa did not maintain an emergency department log. We extracted data on all patients listed in the emergency department log book and whose discharge diagnosis mentioned either asthma, chronic bronchitis, or emphysema. The data extracted included diagnoses, age, sex, town of residence, hospital visited, date and time of visit, and disposition. Because we did not extract personal identifiers, it is possible that the same person could have been counted on several different occasions. People who were not residents of the island of Hawaii were coded as either being from other islands in the Hawaiian archipelago, from the mainland United States, or from other countries.

We recoded all of the data entries to make the diagnoses uniform and to make the town recorded conform to a standard census district. The diagnoses were coded as either a primary or secondary diagnosis of asthma, or a primary or secondary diagnosis of COPD. Each entry had only one diagnosis, and in those cases where both asthma and COPD were listed in the discharge diagnoses, we used the diagnosis that appeared first. We then entered the recoded data into a computerized data set and verified the data manually using the data-entry sheets.

We used census data from both the 1980 and 1990 U.S. Census.

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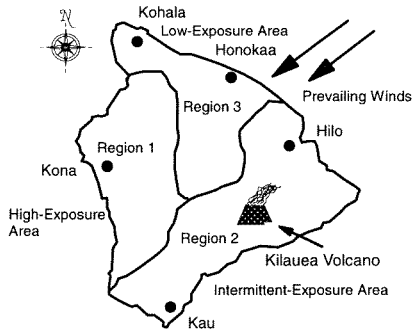
We determined annual intercensal population estimates for each of the 12 census districts on the island by linear interpolation, using 1980 and 1990 age-distribution breakdowns for each census district to estimate the population size for each age group from 1980 to 1991. We used the population estimates to calculate annual age-adjusted and population-adjusted rates.

We divided the island into three regions on the basis of presumed exposure of the population of each area to volcanic air pollution (high, intermittent, or low), along census tract lines (Fig 1). This classification was made on the basis of the consensus of two clinicians who treat patients on the island. Population-based air-pollution data were not available for the years 1981 to 1991.

We calculated annual rates of emergency department visits for asthma (as either the primary or secondary diagnosis) and COPD (as either the primary or secondary diagnosis) for seven age groups in each of these regions. We then calculated the age-adjusted annual rate for each region and the rate ratio (RR) and its 95% confidence intervals (CIs), comparing the period from 1987 to 1991 with the period 1981 to 1986, for each age group in each region and then for each region, using an age adjustment.[6] We used the statistical program SAS (SAS Institute, Cary, NC) for these analyses. Additionally, we calculated annual ratios between the high-exposure region and the intermittent-exposure region using a weighted Mantel-Haenszel stratified analysis available in Epi-Info 5.01 (Centers for Disease Control and Prevention, Atlanta, Ga). We did not calculate annual rate ratios between the low-exposure region and either of the other regions because we did not have data from one hospital that was located in the low-exposure region.

Fig 1.—Map of the island of Hawaii showing Kilauea Volcano, the three exposure regions, and the locations of the five hospitals.



Methods Part II

We used the same emergency room data base described above in this part of the study, but limited our analysis to patients who were treated at the Hilo Hospital emergency department and had a diagnosis of asthma, reactive airways disease or related conditions.

Data on volcanic activity over the study period were obtained from researchers at the U.S. Geologic Survey (Terry Gerlach, U.S. Geologic Survey, August 1993).

Meteorologic data were obtained from Hawaii Volcanoes National Park. A weather station has been operational from September 1986 to the present at a site near Kilauea Volcano. This weather station, which is at an elevation of approximately 4,000 feet, is not influenced by daily variations in wind direction (oceanward in the evening and landward during the day) that affects weather stations close to the coast of an island. We used hourly wind direction, hourly wind speed, and hourly temperature. For each hour, we classified the wind direction as blowing from the west (compass direction between 170° and 340°), blowing from the east (compass direction between 0° and 170°), or neither. We classified an hourly wind speed as low if it was less than the 25th percentile of all the hourly wind speeds (3.9 miles per hour) and classified an hourly temperature as low if it was less than the 25th percentile of all the hourly temperatures (13.5° centigrade). We then summed wind direction from the west and east, low wind speed, and low temperature for each day.

We summed both emergency department visits and meteorologic factors over a 7-day period (Saturday to Friday) to determine weekly counts. For the meteorologic factors, we then divided the sum by the total number of hours that week that the variable was measured to determine a proportion. To calculate categorical variables for meteorologic factors, we determined the highest quartile for wind direction from the west (greater than 10.8% of total hours per week), and the median for low wind speed (15.0% of total hours per week) and low temperature (17.8% of total hours per week) and classified each week accordingly. We also determined quartiles of the wind speed and temperature factors, which we used in the linear regressions.

We determined monthly and annual emergency department visits for asthma. We used 1980 and 1990 census data to estimate annual populations for the region that Hilo Hospital serves, and used these estimates to adjust the visits in the years 1982 to 1991 to the 1981 population.

Statistical analyses were done using the statistical programs SAS and SPIDA (Statistical Computing Laboratory, New South Wales, Australia). We calculated the correlation coefficients between weekly emergency department visits and the meteorologic factors as either continuous or categorical variables. Because meteorologic factors are related to month of the year, we divided each year into three 4-month seasons, and used these divisions, rather than months, as a seasonal indicator. We included this seasonal indicator in our multiple linear regression analyses, using the SAS procedure REGRESS. Wind direction from the west was the main variable of interest. We also assessed interaction between this variable and other meteorologic factors. Additionally, we stratified the data into weeks with low and high wind speeds and temperatures. We then did t-tests, using emergency department visits as the dependent variable, between weeks with and without western winds (as a categorical, independent variable) present.

We used the generalized estimating equation analytic program from SPIDA to repeat regression analyses while controlling for autoregression in our model. We did this by grouping the data into four-month seasons and treating these groups as independent. We used independent and exchangeable correlation structures in this analysis, and controlled for wind speed and temperature.

Results Part I

During the study period, there were 12,539 visits (6,242 females and 6,297 males) for asthma or COPD to the four emergency departments. The diagnoses varied by age, with asthma more prevalent among younger people (younger than age 45 years) and COPD more prevalent among older people (older than age 45 years, data not shown). Similarly, the disposition of each patient visit also varied by age, with a higher percentage of older patients admitted to either the hospital or the intensive care unit than were younger patients (data not shown). Of the 12,539 patients who sought treatment for asthma or COPD, 10,078 (80.4%) were discharged to their home, 1961 (15.6%) were admitted to the hospital, 455 (3.6%) were admitted to the intensive care unit, 5 (0.1%) died, and 40 (0.3%) were transferred to another facility.

Table 1.—Number and Percentage of Patients who Sought Treatment for Asthma or Chronic Obstructive Pulmonary Disease in Four Hospital Emergency Departments by Age Group and Hospital, island of Hawaii, 1981 to 1991.

	Age Group (in years)							
Hospital	0 to < 5	5 to < 15	15 to < 25	25 to < 45	45 to < 65	65 to <75	> 75	Total
Kona	399 (14.1%)	552 (19.6%)	244 (8.6%)	552 (19.6%)	566 (20.1%)	309 (11.0%)	201 (7.1%)	2823
Kohala	100 (17.0%)	233 (39.7%)	50 (8.5%)	68 (11.6%)	44 (7.5%)	33 (5.6%)	59 (10.1%)	587
Hilo	1963 (22.4%)	1943 (22.2%)	885 (10.1%)	1616 (18.4%)	1249 (14.3%)	675 (7.7%)	435 (5.0%)	8766
Kau	41 (11.3%)	139 (38.3%)	52 (14.3%)	47 (13.0%)	24 (6.6%)	25 (6.9%)	35 (9.6%)	363
Total	2503	2867	1231	2283	1883	1042	730	12539

The percentages are a proportion of the row total and may not add up to 100% because of rounding.

Table 2.—Disposition of Patients Seeking Treatment for Asthma and Chronic Obstructive Pulmonary Disease at Four Hospital Emergency Departments, by Hospital, island of Hawaii, 1981 to 1991.

Hospital	Number and Percentage of Patients Discharged	Number and Percentage of Patients Admitted to Hospital	Number and Percentage of Patients Admitted to Intensive Care Unit	Number and Percentage of Patients Who Died	Number and Percentage of Patients Transferred to Other Facility	Total
Kona	1957 (69.3%)	696 (24.7%)	155 (5.5%)	5 (0.2%)	10 (0.4%)	2823
Kohala	506 (86.2%)	59 (10.1%)	0 (0.0%)	0 (0.0%)	22 (3.8%)	587
Hilo	7298 (83.3%)	1161 (13.2%)	300 (3.4%)	0 (0.0%)	7 (0.1%)	8766
Kau	317 (87.3%)	45 (12.4%)	0 (0.0%)	0 (0.0%)	1 (0.3%)	363
Total	10078	1961	455	5	40	12539

The percentages are a proportion of the row total and may not add up to 100% because of rounding.

Both the distribution of patient age and the disposition of the patient varied by hospital (Table 1, Table 2). Hilo Hospital had a higher percentage of visits by patients younger than age 15 years than did Kona Hospital (45% vs 34%, $p < 0.001$) and had a lower percentage of visits by patients older than age 45 than did Kona Hospital (27% vs 38%, $p < 0.001$) (Table 1). As one would expect, Kona Hospital had a higher proportion of patients whose diagnosis was COPD (data not shown) and admitted a higher proportion of patients than did Hilo Hospital ($p = 0.005$). We found that the two smaller hospitals in Kau and Kohala had distributions of patient ages that were similar to those found at Hilo Hospital. We also calculated what percentage of patients received care at the hospital close to them. Of the 8,353 patients included in this part of the study who lived close to Hilo Hospital (as determined by census district) 8,272 (99.0%) received their care at the Hilo Hospital emergency department, whereas of the 2,474 patients who lived close to the Kona Hospital, 2,385 (96.4%) received their care at the Kona Hospital emergency department.

Annual age-adjusted and population-adjusted rates of emergency department visits and hospitalizations for asthma did not show a consistent pattern over the study period (Fig 2). Hospitalization rates for asthma were similar among people living in the high-exposure and intermittent-exposure areas ($p > 0.05$ for every year), whereas emergency department visits for asthma were consistently higher among people living in the intermittent-exposure area than among those living in the high-exposure area ($p < 0.05$ for every year). Annual age-adjusted rates of emergency department visits and hospitalizations for COPD showed a different pattern (Fig 3). The high-exposure area consistently had the highest rates, and these rates were significantly higher in some years when volcanic activity was increased (1983 and 1988 to 1990, $p < 0.05$).

The overall age-adjusted and population-adjusted rate ratios for emergency department visits by people with asthma and COPD and hospitalizations for asthma and COPD, when we compared data for 1987 to 1991 with data for 1981 to 1986, were similar in all three regions of the island (Table 3). Both the emergency department visit rates and the hospitalization rates had increased in all three regions.

Results Part II

During the study period there were 7,993 emergency department visits for asthma to Hilo Hospital. Females made slightly more visits than males (4,032 vs 3,959). Children younger than age 16 made 3,895 (48.7%) visits. Most of the patients were discharged home (6,888, 86.2%).

Mean weekly visits increased from 11.4 in 1981 to 18.2 in 1991 (Table 4). After adjusting the population to the 1981 baseline population, we found that the mean weekly visits increased from 11.4 to 15.2. Figure 4 illustrates the weekly emergency department visits for asthma at Hilo Hospital, along with the volcanic activity over this period, 1981 to 1991.

Figure 5 shows the monthly patterns of emergency department visits for asthma, and how these patterns varied during different time periods. Multiple regression analysis showed the weekly means of emergency department visits during the months of June, July, and August to be significantly lower ($p < 0.01$) than those during the other months in 1983 to 1986 and 1987 to 1991, but not in 1981 to 1982.

For the 225 weeks for which we had data available, we found that weekly emergency department visits were positively correlated with the weekly percentage of hourly winds from the west (Pearson correlation coefficient (r) = 0.21, $p = 0.002$), positively correlated with the weekly percentage of hourly low wind speeds ($r = 0.145$, $p = 0.038$), positively correlated with the weekly percentage of low temperatures ($r = 0.20$, $p = 0.003$), and negatively correlated with the weekly percentage of hourly winds from the east ($r = -0.22$, $p = 0.002$). Figure 6 displays weekly emergency department visits and weekly percentages of hourly winds from the west. Meteorologic factors varied by month (Fig 7).

Emergency department visits were increased during those weeks that had winds from the west more than 10.8% of the time, and during those weeks that had low temperatures more than 17.8% of the time (Table 5). We did not detect a relationship between weeks

Fig 2.—Annual age-adjusted rates for emergency department visits and hospitalizations for asthma during 19811991, island of Hawaii. We used adjusted rate ratios to determine the significance between the high-and intermittnet-exposure areas for each year.

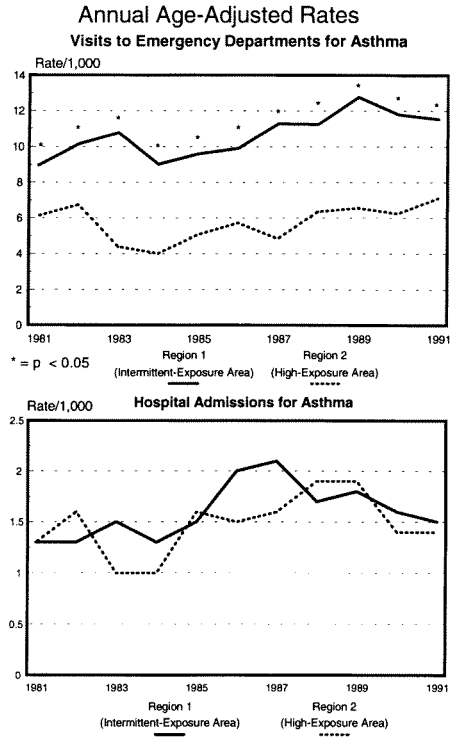


Fig 3.—Annual age-adjusted rates for emergency department visits and hospitalizations for chronic obstructive pulmonary disease (COPD) during 1981 to 1991 on the island of Hawaii. Age-adjusted rate ratios were used to determine the significance between the high-and intermittent-exposure areas for each year.

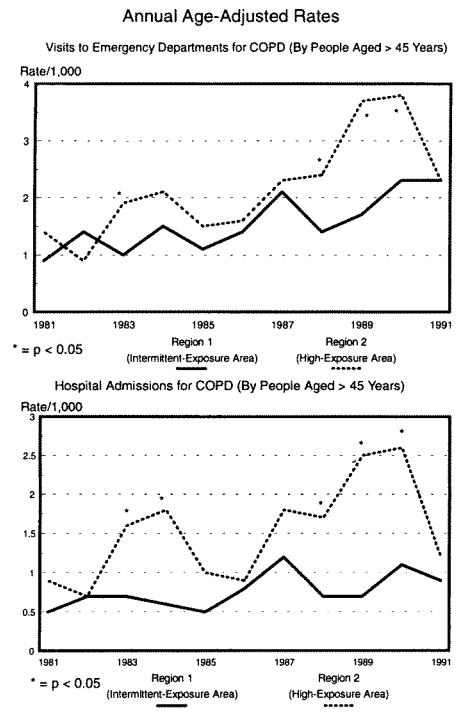


Table 3.—Age-Adjusted Rate Ratios, by Region, for Visits to Hospital Emergency Departments and Hospitalizations for Asthma and Chronic Obstructive Pulmonary Disease (COPD), island of Hawaii, 1981 to 1991.

	Region 1 (High-Exposure Area) RR (95% CI)*	Region 2 (Intermittent-Exposure Area) RR (95% CI)*	Region 3 (Low-Exposure Area) RR (95% CI)*
Emergency Department Visits for Asthma	1.17 (1.07, 1.27)	1.21 (1.15, 1.26)	1.26 (1.03, 1.53)
Hospitalization for Asthma	1.24 (1.03, 1.48)	1.17 (1.04, 1.32)	1.70 (0.96, 3.01)
Emergency Department Visits fro COPD	1.87 (1.52, 2.29)	1.66 (1.43, 1.92)	2.35 (1.18, 4.68)
Hospitalizations for COPD	1.76 (1.38, 2.24)	1.54 (1.25, 1.90)	2.39 (1.03, 5.53)

* Rate Ratio (RR) and 95% Confidence Intervals (CI), comparing age-adjusted rates in 1987 to 1991 to 1981 to 1986.

with low wind speeds and emergency department visits. The percentage of hourly winds from the west was higher during weeks with low temperatures and low wind speeds than it was during weeks with high temperatures and high wind speeds (Table 5). When we stratified the data into weeks with low wind speed and weeks with high wind speed, we found that western winds were associated with an increase in emergency department visits in both strata (Table 6). When we stratified the data into weeks with high temperatures and weeks with low temperatures, we found that western winds were associated with an increase in emergency department visits in weeks with high temperatures, but not during weeks with low temperatures.

We tested for, and did not detect, interactions between wind direction and wind speed or temperature in our multiple regression model. In the final model (Table 7), western winds accounted for a 16% increase in emergency department visits for asthma at Hilo Hospital, after we adjusted for other low wind speed, low temperature, year and season.

In the linear generalized estimating equations, where we grouped the data by year and season to control for autocorrelation, wind direction from the west accounted for a 15% increase in emergency department visits after controlling for wind speed and temperature ($p = 0.005$).

Discussion

The first part of this study examined the trends in emergency department visits for asthma and COPD on the island of Hawaii from 1981 to 1991. We were interested in determining whether there was any change in this trend after Kilauea Volcano began erupting intermittently in 1983 and continuously in 1986.

We did not have air quality data available to validate our high-exposure, intermittent-exposure, and low-exposure regions; instead, we used the consensus of two physicians who treat patients living on the island to determine these regions. Although these divisions seem reasonable, they may not accurately reflect actual exposures to volcano-generated air pollution.

We evaluated an 11-year period in which people had visited emergency departments for the treatment of asthma or COPD. We were able to demonstrate a difference in emergency department utilization between the two largest hospitals: Kona and Hilo. Hilo Hospital tended to treat a greater number of younger patients (younger than age 15 years) and to admit fewer of them, whereas Kona Hospital tended to treat a greater number of older patients

Fig 5.—Monthly emergency department visits for asthma to Hilo Hospital, Hawaii, adjusted to 1981 population for the region that Hilo Hospital services.

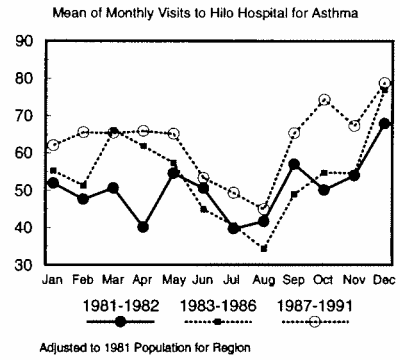
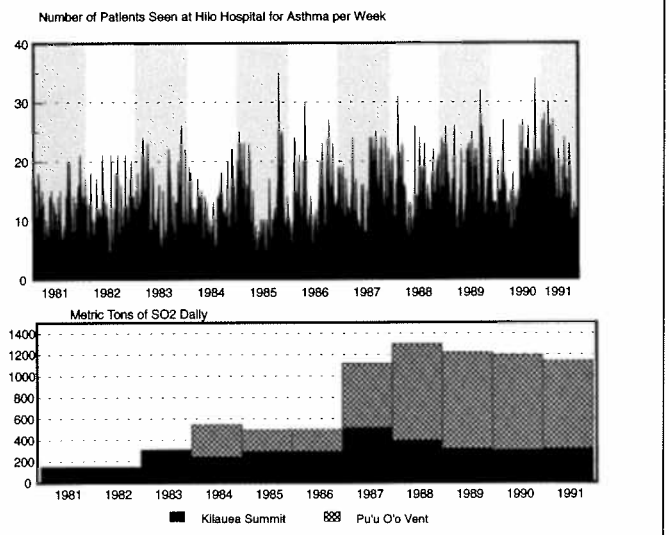


Fig 4.—Weekly emergency department visits for asthma to Hilo Hospital, Hilo, Hawaii, and volcanic activity, as determined by sulfur dioxide emissions, for the years 1981 to 1991.



(older than age 45 years) and to admit more of them. The reasons for the difference in utilization patterns are unclear but may be related to the differences in the communities that surround these two hospitals. This difference may have affected the outcome of the study, especially if children in the Kona area, which is thought to have high exposure to volcanic air pollution, were more likely to receive care for their asthma exacerbations at physician's offices than at the hospital's emergency department. We were not able to obtain data from the Honokaa Hospital, where emergency department logs were not maintained during 1981 to 1991. This small hospital is located in a low-exposure region from which it draws its patients. The absence of data from this hospital would cause the estimates of asthma and COPD rates among people living in the low-exposure region to be falsely low, but this absence would not be expected to affect these rates among people living in the high-exposure or intermittent-exposure regions of the island.

Annual age-adjusted rates for both emergency department visits and hospital admissions for asthma varied by the region of the island. Although people living in the intermittent-exposure area had a higher rate of emergency department visits than did people living in the high-exposure area, the hospitalization rates for people living in either area were similar in all years of the study. This finding suggests that the people with asthma who were treated at the hospital in the intermittent-exposure region (Hilo) had less severe illness than those who sought treatment at the hospital in the high-exposure area (Kona). Other possibilities include a diagnostic bias at Hilo Hospital (physicians may have been more likely to list a discharge diagnosis as asthma), a difference in emergency department utilization between Hilo and Kona Hospitals, or a difference in access to primary care physicians between the Hilo and Kona communities. Conversely, in 1983 and 1988 to 1990, age-adjusted rates for both emergency department visits and hospitalizations for COPD were higher in the high-exposure region than they were in the intermittent-exposure region.

Age-adjusted and population-adjusted rates of emergency department visits for both asthma and COPD were higher in 1987 to 1991 than in 1981 to 1986; the same was true for hospitalizations for asthma and COPD. This relationship was detectable in areas of the island thought to have high, intermittent, and low exposures to volcanic air pollution. The reasons for these higher rates are unclear. One possibility is that the increase we observed was unrelated to the volcanic eruption. Another possibility is that, because people travel to all areas of the island, their residence may not accurately reflect their exposure to volcanic air pollution. Yet another possibility is that volcanic air pollution affects the entire island to some degree.

National estimates of hospital discharge rates for asthma increased 4% from 1980 to 1990.[7] In this study, we found that hospitalization rates for asthma, after adjusting for age and population, increased 20% and varied by region. The increasing morbidity and mortality of asthma nationally is thought to be related to several factors, including allergen exposure, lack of access to care, inappropriate medication use, and poor air quality. We do not have any data on allergens that are present on the island or how their levels may have changed over the study period. More than 98% of Hawaii residents have medical insurance,[8] so most would have access to either a primary care provider or to the emergency department. We do not have data on medication use by residents, but would not expect this to vary dramatically from such use by people in the rest of the country. We did not collect data on emergency department visits for bronchitis or pneumonia for this 11-year period. These conditions would be expected to affect a larger portion of the population than asthma or COPD and might be more sensitive indicators of the effects of volcanic air pollution.

The results of the second part of the study suggest that, after controlling for other meteorologic factors such as wind speed and temperature, winds from the west are associated with an increase in emergency department visits for asthma at Hilo Hospital. There is a strong, independent, seasonal component to both emergency department visits for asthma and the other meteorologic factors that were measured. Unfortunately, we do not have meteorologic data prior to 1986 to determine whether this pattern was similar when there was less volcanic activity.

Other researchers have demonstrated a relationship between meteorologic factors and hospitalizations for asthma exacerbations.[9,10] Results of a study on Oahu demonstrated a relationship similar to that seen in our study between unusual wind directions and emergency department visits for children with wheezing.[11] In that study, the magnitude of the effect of wind direction was about 20% of the effect of temperature, whereas in our study, the magnitude of the effect of wind direction was greater than that of temperature.

Air quality factors, including levels of sulfur dioxide,[10,12] ozone,[13] acid aerosols,[14] and organic dusts[15] have been linked to respiratory morbidity and mortality in some studies. Sulfur dioxide is the main

Table 4.—Population estimates of the Hilo Hospital catchment area and mean weekly emergency department visits for asthma, unadjusted and adjusted to 1981 population, for 1981 to 1991.

Year	Estimated Population	Inadjusted Weekly Mean Visits	Adjusted Weekly Mean Visits
1981	56,833	11.4	11.4
1982	57,958	12.1	11.9
1983	59,083	13.9	13.4
1984	60,208	12.1	11.4
1985	61,333	13.3	12.4
1986	62,458	13.7	12.5
1987	63,583	15.0	13.4
1988	64,708	15.6	13.7
1989	65,833	17.7	15.3
1990	68,083	16.8	14.2
1991	69,958	18.2	15.2

Table 5.—Mean emergency department (ED) visits to Hilo Hospital, Hawaii, for asthma and mean percentage of weekly winds from the west stratified by weeks with or without low wind speeds, low temperatures, and winds from the west. The P values compare the yes values to the no values in each category.

Variable		N	ED Visits	P	Percentage of Winds from West	P
Low Wind Speed	No	113	15.6	.210	0.9	< .000
	Yes	112	16.5		17.3	
Low Temperature	No	111	14.7	< .000	5.9	.003
	Yes	112	17.4		12.3	
Winds from West	No	168	15.4	.003	1.3	< .000
	Yes	57	17.9		31.8	

pollutant generated at Kilauea Volcano (Terry Gerlach, U.S. Geologic Survey, August 1993), in amounts that far exceed those generated by coal-burning power plants.[16] Additionally, hydrochloric acid aerosols are generated when hot lava enters the ocean.[17] We did not have population-based air quality data available to us. The meteorologic station, located near the Kilauea Volcano's summit, documented high levels of sulfur dioxide when the wind was blowing toward the monitor (data not shown). Although tourists visit this area, few people live near this monitoring station, and the air pollutant levels measured there would likely not be correlated with population exposures in Hilo. Additionally, the largest source of sulfur dioxide is the Puu Oo vent (Fig 5), located eight miles closer to Hilo than the summit.

We used the meteorologic data from the summit of Kilauea Volcano, believing that these data would best reflect the general meteorologic conditions on the eastern side of the island, without being affected by the daily wind variations that affect the more coastal monitors. The overwhelming majority of the winds measured at this weather station were the typical eastern trade winds. The weekly percentage of western winds varied by month, with June, July, and August having the lowest percentage, and October, December, and February having the highest percentage. Even in the months with the highest percentages, however, western winds accounted for only 25% of the total weekly winds.

We used different methods to determine the relationship between wind direction and emergency department visits. All methods demonstrated an increase in weekly visits of approximately 15% associated with western winds when we controlled for other factors. This finding may be related to air quality factors and volcano-generated air pollution. Another cause for this finding might be allergens or molds blown into the area from the east central part of the island. Other factors, such as respiratory infections or influenza epidemics, also may be important.

Limitations of both parts of this study include a possible self-selection process, diagnostic bias, and lack of environmental or personal exposure data. Some physicians have reported that some of their patients who thought that the volcanic air pollution was adversely affecting their health either moved to a different part of the island or moved off the island altogether. If this observation is true, those residents who remained behind in the high-exposure areas would be a healthier subgroup, people who were possibly less affected by the effects of volcanic air pollution. Our extraction method was dependent on the diagnosis listed in the emergency department log book. Different physicians might give a similar disease process different diagnoses, which might have affected our results if these alternative diagnoses were not included in data extraction. A final limitation is that we did not have regional or personal exposure data. This limitation makes this study an ecologic one, which can be used to generate but not prove hypotheses.

Some of the results of our study support the hypothesis that volcanic air pollution affects respiratory health on the island of Hawaii, while other results do not. We found that emergency department visit rates and hospitalization rates for both asthma and COPD increased in all regions of the island of Hawaii during the period 1987 to 1991, including those areas that presumably have less exposure to volcanic air pollution. Conversely, we detected a higher rate of both emergency department visits and hospitalizations for COPD on the high-exposure, western side of the island during 1983 and 1988 to 1990 than on the intermediate-exposure, eastern side of the island during those years. We did not see, however, a similar effect in asthma hospitalizations, and we found that the rates of emergency department visits for asthma were much higher on the intermittent exposure side of the island. On the other hand, during weeks when winds were blowing towards the Hilo side of the island, 15% more people went to the emergency room in Hilo because of asthma. We do not have air quality data and cannot determine whether these findings are related to volcano-generated air pollutants or other factors. Further investigations of asthma and other respiratory disease on this island should include population-based air-quality monitoring, that measures levels of sulfur dioxide, fine respirable particulates, and acid aerosols.

Use of trade names is for identification only and does not constitute endorsement by the U.S. Public Health Service or the U.S. Department of Health and Human Services.

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Fig 7.—Weekly percentage of low temperature hours, low wind speed hours, and hours with winds from the west, by month over the time period 1987 through 1991, Hilo, Hawaii.

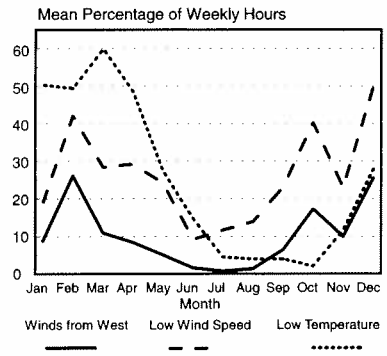

Fig 6.—Weekly emergency department visits for asthma to Hilo Hospital, Hilo, Hawaii, and weekly percentage of hours with winds from the west, measured at the Kilauea summit, for the years 1987 through 1991.

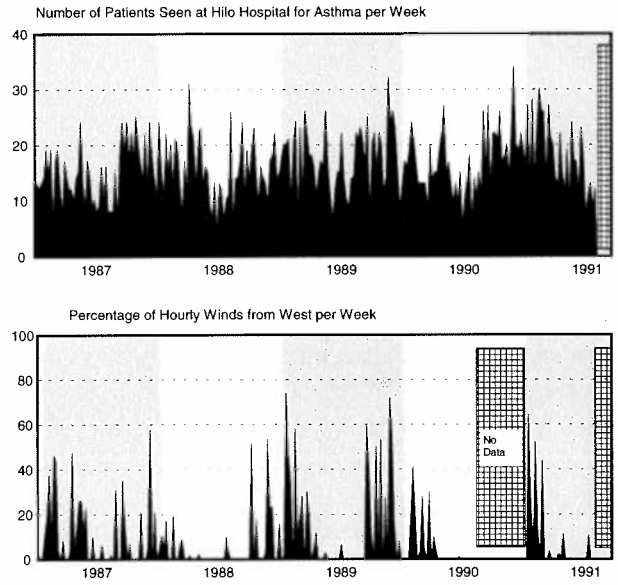

Table 6.—Mean number of emergency department (ED) visits to Hilo Hospital, Hilo, Hawaii, for asthma by weeks, with western winds, stratified by weeks of high and low wind speeds and weeks of high and low temperatures.

	Variable		N	ED Visits	P
Weeks of Low Wind Speed	Winds from West	No	57	15.4	.020
		Yes	55	17.8	
Weeks of High Wind Speed	Winds from West	No	111	15.5	< .000
		Yes	2	23.0	
Weeks of Low Temperature	Winds from West	No	71	17.1	.490
		Yes	41	17.9	
Weeks of High Temperature	Winds from West	No	95	14.1	.009
		Yes	16	18.1	

Table 7.—Multiple linear regression results of variables in the final regression model for mean emergency department visits to Hilo Hospital for asthma, 1986 to 1991.

Variable	Coefficient	t	p
Weeks with Western Wind	2.50	2.41	.017
Weeks with Low Wind Speed (Quartiles)	-0.93	2.06	.041
Weeks with Low Temperature (Quartiles)	1.01	2.35	.019
Year*			
1988	1.30	1.37	.172
1989	3.84	3.75	< .000
1990	2.96	2.45	.015
1991	4.17	3.44	.001
Season**			
Spring (January - April)	1.69	1.58	.115
Fall (September - December)	4.79	5.17	< .000

R^2=0.22; F=6.63

* 1986 to 87 were the control years

** Summer (May to August) was the control season

References

1. Feinleib M, Rosenberg HM, Collins JG, Delozier JE, Pokras R, Chevarley FM. Trends in COPD morbidity and mortality in the United States. *Am Rev Respir Dis* 1989;140:S9-18.
2. Jackson R, Sears MR, Beaglehole R, et al. International trends in asthma mortality: 1970 to 1985. Chest 1988;94:914-9.
3. Sly RM. Mortality from asthma. *J Allergy Clin Immunol.* 1989; 84:421-34.
4. Bailey WC, Clark NM, Gotsch AR, et al. Asthma prevention. *Chest.* 1992; 102; 216s-231s.
5. Morrow JW, Morgan EJ, Furuike AN, et al. Characterization of volcanic aerosol in two populated areas on the island of Hawaii: First year findings of a 3-year investigation (Presented at Air and Waste Management Association meeting, June 16-21, 1991, Vancouver, British Columbia.
6. Rothman KJ. *Modern Epidemiology.* Boston, Mass: Little, Brown and Co; 1986.
7. Centers for Disease Control and Prevention. Asthma–United States, 1980 to 1990. MMWR 1992;41:733-35.
8. State of Hawaii Department of Health. *Annual Report Statistical Supplement 1989.* Honolulu, Hawaii, 1991.
9. Mao Y, Semenciw R, Morrison H, et al. Seasonality in epidemics of asthma mortality and hospital admission rates, Ontario, 1979 to 86. *Can J Public Health.* 1990;81;226-8.
10. Richards W, Azen SP, Weiss J, et al. Los Angeles air pollution and asthma in children. *Ann Allergy.* 1981;47:348-54.
11. Yamamoto LG, Iwamoto LM, Yamamota KS, et al. Effect of environmental conditions on emergency department use by wheezing children. *Ann Emerg Med.* 1993; 22:523-9.
12. Tseng RYM, Li CK. Low-level atmospheric sulfur dioxide pollution and childhood asthma. *Ann Allergy.* 1990;65:379-83.
13. Bates DV, Sizto R. Relationship between air pollutant levels and hospital admissions in southern Ontario. *Can J Public Health.* 1983;74:117-22.
14. Ostro BD, Lipsett MJ, Wiener MB, et al. Asthmatic response to airborne acid aerosols. *Am J Public Health.* 1991;81:695-702.
15. Anto JM, Sunyer J, Rodriguez-Roisin R, et al. Community outbreaks of asthma associated with inhalation of soybean dust. *N Engl J Med.* 1989;320:1097-1102.
16. U.S. Environmental Protection Agency. Air quality criteria for particulate matter and sulfur oxides. Research Triangle Park, NC: Environmental Criteria and Assessment Office, 1982b. EPA-600/8-82-029 (PB 54-156801/reb).
17. National Institute for Occupational Safety and Health. Hazard evaluation and technical assistance report: National Park Service, Hawaii Volcanoes National Park. Cincinnati, Ohio. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, NIOSH Report No. RDHETA 90-179-2172, 1990.